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Capillary Containment of Liquids in a Microgravity Environment:
Shear-stabilization and Rupture

Final Technical Report

Cornell University
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NAG3-801 (NASA Contact: J. Salzman)
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Project Objectives and Description: The influence of liquid motion on the containment of liquids by surface tension is studied. Modification of the capillary instability by shear-related forces is important to a wide variety of processing applications (materials and/or chemical) and is especially important in a low-gravity environment. We ask two contrasting questions: can motion enhance the stability of a configuration (containment) and what motions are generated when a configuration is unstable (collapse)? The answer to the first question is "yes" and we explore the extent to which stabilization can occur. The second question is important, for example, to droplet generation during break-up or collapse. Both questions are addressed by a combination of theory and experiment closely tied to one another.

Results: We have

(i) discovered and mapped out, in a variety of contexts, the windows in parameter space where hydrodynamic shear forces can stabilize capillary break-up in long cylindrical interfaces according to linear stability theory: rod flow (isothermal and thermocapillary-driven), tube flow, and core-annular rod flow. In particular, the physical mechanism of stabilization has been identified.

(ii) designed, built, and tested an apparatus capable of shear-stabilization in a parameter range where theory suggests stabilization may occur. Experiments show reasonable agreement with theory. In the course of the experimental investigation, a pressure drop method of fine-tuning the neutral buoyancy approach to low gravity simulation (Plateau chamber) has been discovered.

(iii) developed a simple analog experimental system, the soap-film bridge, by means of which many of the fundamental influences of motion on stability may be studied. The soap-film bridge has illustrated details of the collapse phenomenon never before documented.

These results are reported in detail in the publications listed below.

Education: The following scientists have been trained through the support of the grant.

PhD Students: M.J. Russo, S.A. Cryer, and B.J. Lowry

Postdoctoral Associate: H.A. Dijkstra

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Publications
(support from NAG3-801)

Publications in Journals:

1. Russo, M.J., and P.H. Steen, "Shear-stabilization of the Capillary Breakup of a Cylindrical Interface," Phys. Fluids A 1:1926-1937 (1989).
2. Dijkstra, H.A., "The coupling of Marangoni and Capillary Instabilities in an Annular Thread of Liquid," J. Colloid Interface Sci. 136, 151-159 (1990).
3. Dijkstra, H.A., and P.H. Steen, "Thermocapillary Stabilization of the Capillary Break-up of an Annular Film of Liquid," J. Fluid Mech. 229 (1991).
4. Cryer, S.A., and P.H. Steen, "Collapse of the Soap-film Bridge: Quasistatic Description," J. Coll. Int. Sci. 154(1) (1992).
5. Dijkstra, H.A. "The coupling of interfacial instabilities and the stabilization of two-layer annular flows," Phys. Fluids A 4 (9), 1915-1928 (1992).
6. Dijkstra, H.A. "Erratum: 'The coupling of interfacial instabilities and the stabilization of two-layer annular flows'," Phys. Fluids A 5 (6), 1517 (1993).
7. Lowry, B.J. and P.H. Steen, "Stabilization of an Axisymmetric Liquid Bridge by Viscous Flow," Int. J. Multiphase Flow, 20 (2), 439-443 (1994).
8. Lowry, B.J. and P.H. Steen, "Flow-influenced Stabilization of Liquid Columns," J. Coll. Int. Sci. (in press).
9. Lowry, B.J. and P.H. Steen, "Capillary Surfaces: Stability from Families of Equilibria with Application to the Liquid Bridge," (Proc. Roy. Soc. A, accepted).

Publications in Proceedings:

10. Steen, P.H., "Capillary Containment and Collapse in Low Gravity: Dynamics of Fluid Bridges and Columns," Free Boundary Problems: Theory and Applications, v. 3, Longman-Pitman Publishing, Essex, UK (1992).
11. Lowry, B.J. and P.H. Steen, "Flow-influenced Stabilization of Liquid Columns in a Dynamic Plateau Chamber," AIAA Paper 93-0255 (1993).
12. Lowry, B.J. and P.H. Steen, "On the Density Matching of Liquids using Plateau's Method," AIAA Paper 94-0832 (1994).